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Guidance on the Technology Performance Level (TPL) Assessment Methodology

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Contents

Acknowledgments	4
1. Introduction.....	6
1.1 Systems Engineering	6
1.2 Integration of TPL and TRL	7
1.3 Technology vs. Project	7
1.4 Brief Instructions for Use	8
2. Stakeholder Needs and Assessment Guidance	9
Glossary	52
References.....	56

1. INTRODUCTION

This document presents the revised Technology Performance Level (TPL) assessment methodology. There are three parts to this revised methodology 1) the Stakeholder Needs and Assessment Guidance (this document), 2) the Technical Submission form, 3) the TPL scoring spreadsheet. The intended uses of the revised TPL include:

- 3rd party technology assessment e.g. public funding bodies or technical due diligence.
- In house technology assessment for choosing between innovative product alternatives.
- Finance community and OEMs as investors in WEC technology.
- Finance community and OEMs as investors in WEC farm deployments.

The TPL assessment is designed to give a technology neutral or agnostic assessment of any wave energy converter technology. The focus of the TPL is on the performance of the technology in meeting the customer's needs. The original TPL is described in [1, 2] and those references also detail the critical differences in the nature of the TPL when compared to the more widely used technology readiness level (TRL). (Wave energy TRL is described in [3]). The revised TPL is particularly intended to be useful to investors and also to assist technology developers to conduct comprehensive assessments in a way that is meaningful and attractive to investors.

The revised TPL assessment methodology has been derived through a structured Systems Engineering approach. This was a formal process which involved analyzing customer and stakeholder needs through the discipline of Systems Engineering. The results of the process confirmed the high level of completeness of the original methodology presented in [1] (as used in the Wave Energy Prize judging) and now add a significantly increased level of detail in the assessment and an improved more investment focused structure. The revised TPL also incorporates the feedback of the Wave Energy Prize judges.

The highlights of the revised TPL methodology are:

- The new structure and equation formulation more clearly represents energy economics.
- More complete inclusion of investment security and risk.
- Integration of LCoE calculation into the TPL.
- Integration of TPL with TRL (different TPL assessment questions at different TRL).
- Harmonization of TPL with terminology of certification and IEC standards.
- Reconciliation of TPL with Systems Engineering.
- TPL is now assessed using a list of detailed questions as guidance.
- Significantly expanded depth of coverage.

Of note is that the use of this document is made easier through reference of the glossary in section three which provides definitions of critical terms and accompanying information.

1.1 Systems Engineering

The TPL groups and attributes, originally developed through experience in [1], are now recognized as the stakeholder needs, sometimes referred to as the capabilities. The needs of each individual stakeholder have been condensed into a distilled list of needs that ensure the WEC

plant will achieve all the needs of each stakeholder. This list of stakeholder needs (or capabilities) now forms the basis of the technology performance levels.

Tradeoffs in the overall design manifest themselves in the competing capabilities. The assessment guidance that is associated with the capabilities query the technical solutions that a technology has chosen, i.e. they identify which tradeoffs have been selected. For instance, in order to be a low cost design a device should not require a lot of material. However, in order to be able to generate a large amount of electricity the device should be large. Hence as the TPL is assessed on a holistic level, if you choose to favor small amounts of material you will receive a high score there, but it may be balanced by a low score in generation.

The resulting structure of capabilities is as follows:

- C1: Have market acceptable LCoE.
- C2: Provide a secure (low risk) investment opportunity.
- C3: Be reliable for grid operations.
- C4: Be beneficial to society.
- C5: Be acceptable to permitting & certification.
- C6: Be acceptable with respect to safety.
- C7: Be globally deployable.

The capabilities are customer focused rather than technology focused which is in keeping with the Systems Engineering philosophy. The later sections of this document cover these capabilities and provide a series of detailed questions to be answered by the TPL assessor under the capabilities and two nested levels of sub-capabilities. In each case the capabilities and the questions are intended to address the customer needs and so be independent of any technical solutions.

1.2 Integration of TPL and TRL

This revised version of the TPL assessment addresses the question of appropriate levels of detail at different TRL levels. The assessment questions are grouped according to three levels of TRL. The most basic questions are addressed to TRL1 technologies. An expanded more detailed set of questions is addressed to TRL3 technologies and these must also update their answers to the TRL1 questions. Finally, technologies at TRL5 and above must present quantified and verified evidence for expected performance.

1.3 Technology vs. Project

The TPL is designed to be an assessment of the suitability of the technical solution for the customers' needs. As such it is focused on technology assessment to a much greater extent than it is on project assessment. However, in certain questions it is necessary to consider a typical or target deployment location and typical or target wave farm project at that location since these are the context for the ultimate use of the technology and its value creation mechanism. In general, when answering the questions in the assessment at TRL 1 & 3 the technology promoter should

give information for some notional “typical” deployment, plant size (MW) distance from shore, etc., while at TRL 5 the assessment needs to have a real world example of target deployment location and wave farm project.

1.4 Brief Instructions for Use

The revised TPL assessment should follow these broad steps:

- The technology must be described by its “promoter” in the technical submission form.
- The assessor must use the information in the technical submission form to assign a score of high/medium/low to each question in the assessment.
- For each numbered capability or sub-capability the assessor must weigh the high/medium/low scores assigned to the answers in that section and assign a score on a scale of 1-9 to the capability. E.g. all High => 9, mostly High => 8 ... all Low => 1.
- The assessor should enter the score for each capability in the scoring spreadsheet.

2. STAKEHOLDER NEEDS AND ASSESSMENT GUIDANCE

C1. Have market competitive cost of energy

The **electricity** from the wave energy plant may be sold on the day-ahead wholesale electricity market or through a Power Purchase Agreement (PPA). In both cases, the **sale price** of the electricity generated by the wave energy plant shall be **competitive with other energy sources**. However, note that market price may vary among energy sources in some countries. There may be Feed-In Tariffs (FIT) for wave energy or renewable energy sources or there may be Renewable Energy Certificates or Renewable Obligations.

C1.1. Have as low a CAPEX as possible

CAPEX includes **all costs** that occur in the development and construction of a WEC plant **until it starts producing electricity**. The WEC plant should have as low a CAPEX as possible. **Drivers** of CAPEX are **design, manufacturability, transportability, installability**. It includes costs related to grid connection.

C1.1.1. Be a low cost design

A WEC plant should have a simple design, have as small a number of components/sub-systems as possible, with many suppliers for the components and sub-systems. It should minimize the required material quantities and it should make use of low cost material types. It may maximize recycling opportunities in order to provide additional revenues in the end of the lifetime.

TRL1
<ul style="list-style-type: none">• How many systems (systems that collect wave power, aggregate power, deliver power, and control position) will comprise the plant? For each system identify the number and technology class.• For the system that collects wave power, please answer the following questions:<ul style="list-style-type: none">a. Where in the water column is this system located?b. What is the displaced volume?c. What is the dominant material type and what is its raw cost?d. How many and what is the displaced volume for structural members that are not intended to collect wave power?e. How many point loads (heave plate, mooring lugs, PTO, end stops) are in this system? Identify the type and number.f. What is the total number of distinct physical configurations?• Where in the water column is the system that aggregates power?• For the system that controls position, please answer the following questions:<ul style="list-style-type: none">a. What is the mooring concept (catenary, tension, etc.) and what is the

<p>technology class?</p> <p>b. Does the concept require a certain deployment depth?</p> <p>c. How many total connections points are there on the collect wave power system and on the sea floor?</p>
TRL3
<p>Update the answers to TRL1 plus answer the following questions:</p> <ul style="list-style-type: none"> • How many sub-systems comprise each system (mechanisms that collect wave power, aggregate power, deliver power, and control position)? For each system identify the number of sub-systems and their technology class. • For the system that collects wave power, please answer the following questions: <ul style="list-style-type: none"> a. Using simplified analysis that applies to the lifecycle stages including assembly, installation, and operations please answer the following: <ul style="list-style-type: none"> i. What is the needed material volume, type, and cost? For each material type list: type, volume, cost. ii. What amount of each material type was added to secure against a failure mode? b. What are the magnitudes of the point loads identified previously? What modeling technique was used to identify these magnitudes? c. What are the load cases considered for ULS, ALS and FLS for each system? d. What are the specific capacity factors for the sub-systems within collect wave power considering dynamic analysis? • For the system that aggregates wave power, please answer the following questions: <ul style="list-style-type: none"> a. What is the distance between the aggregators and what is the distance to the systems that collect wave power? b. How many collect wave powers connect to one aggregator and what is the technology class of the connection? c. What are the specific capacity factors for the conduit from collect to aggregate and the other sub-systems considering dynamic analysis? • For the system that delivers wave power, please answer the following questions: <ul style="list-style-type: none"> a. What is the rated power at the point of connection to the grid? b. What is the annual average capacity factor of the conduit that transports power from the aggregators to the grid? What are the specific capacity factors for the conduit that transports power from the aggregators to the grid and the other sub-systems considering dynamic analysis? <ul style="list-style-type: none"> i. If the conduit is an electrical cable, identify the diameter and voltage rating.

<ul style="list-style-type: none"> ii. If the conduit is not an electrical cable, identify the diameter, wall thickness, and material properties. c. What is the typical distance to shore that the aggregated power must travel? <ul style="list-style-type: none"> • For the system that controls position, please answer the following questions: <ul style="list-style-type: none"> a. What is the peak force (ULS, ALS)? b. How will the control position connect to the sea floor and what is the technology class of this connection mechanism? c. What geophysical conditions are required to deploy this concept? d. What is the typical distance between the system that collects wave power and the connection point on the sea floor?
TRL5
<ul style="list-style-type: none"> • Materials and components costs = Sum of costs of materials and components/sub-systems required to make the WECs plant (unit cost and number of components/sub-systems) - recycling revenues • What are the associated results from the considered load cases for ULS, ALS and FLS for each system? • What are the safety levels (load factors) used for ULS, ALS, and FLS? • What are the monitoring costs for the plant over the entire life cycle to ensure environmental acceptability?

C1.1.2. Be manufacturable at a low cost

The WEC plant should be easy and quick to mass produce. It should minimize the need for specialized tools and equipment, highly-qualified workers and dedicated or specialized infrastructure for manufacturing, assembly and storage. The WEC plant may provide cost-offsetting.

TRL1
<ul style="list-style-type: none"> • How many systems (mechanisms that collect wave power, aggregate power, deliver power, and control position) must be manufactured? For each system identify the number. • What is the expected manufacturing facility? Is this facility easily transferable to new locations (including concepts of specialized manufactures that would not be able to set up shop in location)? • What expertise is needed from the workforce (dependent upon: material type, level of tolerances that must be achieved, specialized safety, customized molds, etc.)?

- What is the dominant material type in the system that collects wave power?
- What are the sizes (envelope dimensions) and the mass of each sub-system (structure, mechanism that creates transportable power, etc.) that will comprise the system that collects wave power?
- If it is anticipated to be manufactured, what is the dominant material type in the system that aggregates wave power?
- If it is anticipated to be manufactured, what is the dominant material type in the system that controls position?

TRL3

Update the answers to TRL1 plus answer the following questions:

- How many sub-systems for each system (mechanisms that collect wave power, aggregate power, deliver power, and control position) must be manufactured? For each system identify the sub-system and the number.
- What is the expected manufacturing rate, in day / MW, for all complete systems?
- In order to integrate distinct sub-systems, what mechanisms are employed to achieve and maintain necessary alignment (i.e. in the face of elastic deformation) or what steps are being taken to achieve self-alignment in the face of flexure?
- To what level can the manufacturing techniques be automated for each sub-system and system? (levels: every piece must be hand welded, can use a mold, can use automated fiberglass winding, etc. Suitability of manufacturing process to achieving rounded edges?)
- How many distinct manufacturing techniques (rolling steel, welding steel, winding fiberglass, etc.) must be implemented to achieve the system that collects wave power?
- What are the sizes (envelope dimensions) and the mass of each sub-system (structure, mechanism that combines transportable power, etc.) that will comprise the system that aggregates wave power?
- Are interfaces for sub-systems and components easily identifiable / accessible?

<ul style="list-style-type: none"> • What steps will be taken to ensure that the integration of the sub-systems and components will achieve the quality required? • Are the procedures of assembly efficient and easily implementable?
TRL5
<ul style="list-style-type: none"> • Manufacturing costs = sum of (labour hours * unit cost of labour + hours of use of tools and equipment/infrastructure * unit cost of tools and equipment/infrastructure + hours of storage * unit cost of hour of storage) - Cost offsetting

C1.1.3. Be inexpensive to transport (excluding install)

The WEC plant components, sub-systems and system should be built close to the manufacturing and/or deployment site to minimize shipping and/or transportation costs. It should be transportable in any weather conditions.

TRL1
<ul style="list-style-type: none"> • How will each system (mechanisms that collect wave power, aggregate power, deliver power, and control position) be transported to the installation staging point (e.g. port location)?
TRL3
<p>Update the answers to TRL1 plus answer the following questions:</p> <ul style="list-style-type: none"> • For each transported system, answer the following questions: <ul style="list-style-type: none"> a. What are the mass and envelope dimensions? <ul style="list-style-type: none"> i. If the system is being transported as sub-systems, identify the mass and envelope dimensions of the sub-system as well as the number of independent transports required to assemble the system. b. What is the typical transport distance? c. How many competing transport options are available? • What is the anticipated number of transportation trips per plant rating (rating at point of connection)?
TRL5
<ul style="list-style-type: none"> • Transportation costs = sum over all means of transportation of (hours/distance of transportation * unit cost of transportation)

C1.1.4. Be inexpensive to install

The WEC plant systems should be installable in most weather conditions requiring minimal time to complete the installation, utilizing readily available vessels, minimizing the need for skilled workers.

TRL1
<ul style="list-style-type: none"> For each system (mechanisms that collect wave power, aggregate power, deliver power, and control position), please answer the following questions: <ul style="list-style-type: none"> What are the masses and envelope sizes of systems being transported to and maneuvered within the installation area? What typical distance must the installation vessel(s) travel? At TRL 1 simply identifying the general range (on-shore, near-shore, off-shore) is sufficient. How many assembly steps and how many connections must be made at the installation point? What is(are) the expected installation vessel(s), or alternatively is it clear that any installation vessels can be excluded?
TRL3
<p>Update the answers to TRL1 plus answer the following questions:</p> <ul style="list-style-type: none"> How many MW of rated power at point of grid connection can be installed per year considering the weather windows? How many trips from the harbor to the installation point for all systems must be completed per installed MW? For each system (mechanisms that collect wave power, aggregate power, deliver power, and control position), please answer the following questions: <ul style="list-style-type: none"> What are the weather window requirements for installation? What number of competing installation vessels could complete the installation? How many vessels are needed as once for an assembly procedure? How long will each assembly step take? Where in the water column will connections between systems be made? Please identify the systems being connected. What are the expected dynamics of the systems during connection procedures? What percentage of connections / assembly processes is automated vs. manual? What is the distance between systems that installation vessels must maneuver around? For the system that controls position, please answer the following questions:

<ul style="list-style-type: none"> a. What level of accuracy must be achieved on foundation positioning? b. What geophysical conditions are required for the foundations? c. Is any specialized installation equipment needed for this system? <ul style="list-style-type: none"> • For the system that delivers power, is any specialized installation equipment needed for this conduit?
TRL5
<ul style="list-style-type: none"> • Installation costs = sum over all means of installation (vessels, equipment and infrastructure) of (hours of use* unit cost + hours of stand-by*unit cost + mobilization cost) + sum over all labour types (divers) of (labour hours * unit labour cost + hours of stand-by*unit cost + mobilization cost) • What are the geophysical conditions for the proposed WEC Plant? This will influence the cost of both the system that controls position as well as the system that delivers power.

C1.2. Have as low an OPEX as possible

OPEX includes **all costs** that are **necessary to operate and maintain** the WEC plant over its whole service life. The WEC plant should have as low an OPEX as possible. **Drivers** of OPEX are **reliability** (unplanned maintenance) and **durability** (planned maintenance).

C1.2.1. Be reliable

The WEC plant should be highly reliable to avoid costly unplanned maintenance. High reliability is achieved with proven (Technology Class 1) high quality components, by minimizing the number of parts/components subject to well known failure modes (fatigue, wear, abrasion, corrosion, chemical attack, thermal overload, clogging, photolysis) and by avoiding impulsive loads (end-stops, shock loading, snap loads). Cost of repair for systems that are likely to require frequent unplanned maintenance should be low cost.

TRL1
<p>In answering these questions consider the likelihood of UNPLANNED maintenance and the implications of this for OPEX. Consider the cost of repair including the cost of access. E.g. cost of use of boats and ships.</p> <p>For the system(s) that Collect, Aggregate & Deliver Wave Power and the system(s) that Control Position:</p> <ul style="list-style-type: none"> • What is the target OPEX cost for the overall WEC plant?

- What is the technology class for each system in the WEC Plant?
- For each system that might require an intervention what is the expected number and type of vessels employed?
- What are the expected weather window criteria for each maintenance event for each system?
- What is the size & mass of items being transported and maneuvered?

TRL3

Complete in addition to updating TRL1 and consider the same areas.

- What is the maximum array size (MW capacity) that can be serviced by one maintenance vessel (or team of vessels where multiple vessels are needed for a single intervention)?
- What are the anticipated insurance costs?
- What is the technology class for each sub-system in the WEC Plant?
- What is the list of sub-systems that are likely to be subject to well known failure modes and which modes (e.g. fatigue, wear, abrasion, corrosion, chemical attack, thermal overload, clogging, photolysis, other...).

Note: Ultimate stress in main structures in context of extreme events (extreme environmental inputs, 1/50 year storm, etc) should be considered survivability and not reliability.

- For a full list of possible failures in systems and sub-systems what is:
 - a. Cost of spare parts?
 - b. Location of repair or replacement?
 - c. Cost of vessel required?
 - d. Cost of repair and labour
 - e. Other costs?

Note: Refer to FMECA in answering these questions.

- How many systems where the failure rates are unknown or unverified in this application?

- What is the total anticipated number of unplanned maintenance events per MW per year and how will this change over the lifetime of the plant?
- For each sub-system that might require an intervention what is the location of the sub-system within the system and how modular or accessible is it?
- For each sub-system that might require an intervention what is the expected location of the intervention? (factory, on-shore, dry-dock, quay-wall, harbor, in-shore, at-sea)
*No specific guidance on high medium and low, consider implications of answer on **OPEX** in context of other answers in this section. e.g. for maintenance on-shore or at quay wall device must be removed from installation location, for maintenance in-shore or at-sea qualified workers must be transported to the device and must access it safely.*
- For the chosen vessel type(s) and typical/target installation location and required maintenance tasks what is the round trip travel time plus maintenance time for maintenance interventions?
- Are there any factors (non environmental) that add additional constraints to the permit window length? E.g. legislation, maximum time diver can spend underwater
- In the system that collects wave power what is the Length of conduit (e.g. cable/pressure-pipe) used per MW and number of terminations per MW?
- What is the availability and length of time to access spare parts?
- Are the weather window criteria primarily determined by the capabilities of the vessels or the dynamics of the device?
- Is it necessary, for maintenance or other reason, for personnel to transfer to the WEC at sea?
- Where personnel are required enter enclosed spaces in the WEC at sea for maintenance what is the duration required to ventilate the compartment before it is safe to enter?
- Does the array layout allow for easy access for maintenance vessels?

TRL5

What is the estimate of annual average cost of unplanned maintenance?
[average cost of unplanned maintenance = sum over all systems of sum over all modes of failure for each system of ((lifetime of system / MTBF -1) * cost of repair for this failure)]

where cost of repair for each failure is a function of (cost of spare parts, cost of vessels and equipment, hours of mobilization of vessels and equipment, hours of labour, unit labour cost)

C1.2.2. Be durable over the lifetime of the plant

The WEC plant should be highly durable to avoid costly planned maintenance. The WEC plant is ideally made of high durability (long lifetime) components, and the number of parts/components subject to wear, abrasion and erosion is small. Ideally, the durability of plant's components, sub-systems, systems is the same as the lifetime of the plant. Cost of servicing for systems that require planned maintenance should be low cost.

TRL1
<p>In answering these questions consider the PLANNED maintenance and the implications of this for OPEX. Consider the cost of repair including the cost of access. E.g. cost of use of boats and ships.</p> <p>For the system(s) that Collect, Aggregate & Deliver Wave Power and the system(s) that Control Position:</p> <ul style="list-style-type: none"> • What is the target OPEX cost for the overall WEC plant? • What is the technology class for each system in the WEC Plant? • How many systems have a MTBF<lifetime of the WEC Plant? • For each system that requires an intervention what is the expected number and type of vessels employed? • What are the expected weather window criteria for each maintenance event for each system? • What is the size & mass of items being transported and maneuvered?
TRL3

Complete in addition to updating TRL1 and consider the same areas.

- What is the maximum array size (MW capacity) that can be serviced by one maintenance vessels (or team of vessels where multiple vessels are needed for a single intervention)?
- How many systems and sub-systems have a warranty?
- What is the technology class for each sub-system in the WEC Plant?
- How many systems have a MTBF<lifetime of the Plant?
- What is the number of systems that have manufacturer recommended services / inspections over the plant lifetime and how many inspections are required?
- What is the total anticipated number of planned maintenance events per MW per year and how will this change over the lifetime of the plant?
- For each sub-system that might require an intervention what is the location of the sub-system within the system and how modular or accessible is it?
- For each sub-system that might require an intervention what is the expected location of the intervention? (factory, on-shore, dry-dock, quay-wall, harbor, in-shore, at-sea)

*No specific guidance on high medium and low, consider implications of answer on **OPEX** in context of other answers in this section. e.g. for maintenance on-shore or at quay wall device must be removed from installation location, for maintenance in-shore or at-sea qualified workers must be transported to the device and must access it safely.*

- For the chosen vessel type(s) and typical/target installation location and required maintenance tasks what is the round trip travel time plus maintenance time for maintenance interventions?
- Are there any factors (non environmental) that add additional constraints to the permit window length? E.g. legislation, maximum time diver can spend underwater
- Are the weather window criteria primarily determined by the capabilities

<p>of the vessels or the dynamics of the device?</p> <ul style="list-style-type: none"> • Is it necessary, for maintenance or other reason, for personnel to transfer to the WEC at sea? • Where personnel are required enter enclosed spaces in the WEC at sea for maintenance what is the duration required to ventilate the compartment before it is safe to enter? • Does the array layout allow for easy access for maintenance vessels?
TRL5
<p>- Average annual of cost of planned maintenance = sum over all systems of sum over all servicing of (lifetime of plant / time between services * servicing cost)</p> <p>where servicing cost is a function of (cost of spare parts, cost of vessels and equipment, hours of mobilization of vessels and equipment, hours of labour, unit labour cost)</p>

C1.3. Be able to generate large amount of electricity from wave energy

The amount of electricity generation is an essential driver to the **value of the WEC plant**. Large amount of electricity generation enables a high energy yield and hence a high revenue.

C1.3.1. Absorb large amounts of wave energy

The WEC plant needs to capture energy across a wide range of frequencies, heights, approach angles. It is unaffected by tide/current and wind. Negative array interaction are small. Note that availability shall not be taken into account here because it is taken into account in C1.4.

TRL1
<ul style="list-style-type: none"> • What is the target wave resource? • How does the target capture width of the systems that collect wave power compare with existing known technologies? • Is the theoretical limit for energy absorption by the wave power collecting systems units large (# of DoFs and types, orientation, Budal limit)? • Is the swept volume of the wave power collecting systems limited? • Is the energy absorption by the wave power collecting systems sensitive to tidal height, tidal current, wind or wave direction?

<ul style="list-style-type: none"> • If relevant, what is the influence of the mooring systems on energy absorption?
TRL3
<ul style="list-style-type: none"> • What is the annual average of absorbed wave power by the WEC plant? <ul style="list-style-type: none"> a. Provide typical scatter diagram for target deployment site (Joint Probability Distributions (JPD) for wave resource) b. Provide directional power matrix of the wave power collecting systems (taking into account influence of end-stops, mechanical and electrical PTO constraints, external energy/viscous losses) c. Provide estimated array interaction factor matrix
TRL5
<ul style="list-style-type: none"> • What is the annual average of absorbed wave power by the WEC plant? <ol style="list-style-type: none"> 1. Provide time sequence of sea conditions (30 minutes sampling rate) for target deployment site over 10 years. 2. Provide average absorbed power for sea conditions of the time sequence for the wave power collecting systems (taking into account transition time between operational modes). 3. Provide array interaction factor for sea conditions of the time sequence.

C1.3.2. Have high conversion efficiency of extracted energy to electrical energy

The WEC plant power conversion chain should have a small number of conversion steps. Each conversion steps should be highly efficient. Note that availability shall not be taken into account here because it is taken into account in C1.4.

TRL1
<ul style="list-style-type: none"> • At system level: <ul style="list-style-type: none"> a. How many energy conversion steps are there from the wave power collecting systems to Point of Connection? b. For each energy conversion step from the wave power collecting systems to Point of Connection, what is the target average efficiency? c. For each energy conversion step from the wave power collecting systems to Point of Connection, how large is the ratio of peak to mean power at wave period time scale? • For the systems that collect wave power: <ul style="list-style-type: none"> a. At sub-system level, how many energy conversion steps are there? b. At sub-system level, what is the target average efficiency? c. At sub-system level, how large is the ratio of peak to mean power at wave period time scale?

TRL3
<ul style="list-style-type: none"> • What is the annual average of efficiency from absorbed wave power to Point of Connection? <ul style="list-style-type: none"> a. Provide matrix of average power losses from absorbed power to PoC (considering all conversion steps at min. sub-system level, considering the dynamics of the inputs into the sub-systems) b. Provide matrix of recirculated power (e.g reactive control) • What is the annual average of consumed power in ancillary systems? <ul style="list-style-type: none"> a. Provide matrix of average input power in ancillary systems • What is the ratio of peak efficiency to average efficiency?
TRL5
<ul style="list-style-type: none"> • What is the annual average of efficiency by the WEC plant? <ul style="list-style-type: none"> a. Provide time sequence of sea conditions (30 minutes sampling rate) for target deployment site over 10 years b. Provide average power losses for sea conditions of the time sequence from absorbed power to PoC. • What is the annual average of consumed power in ancillary systems? <ul style="list-style-type: none"> a. Provide average power in ancillary systems for sea conditions of the time sequence.

C1.4. Have high availability

Availability is the ratio of the average annual capacity of the plant to the theoretical capacity. Availability is a **revenue driver**. High availability may also increase sales price.

C1.4.1. Be reliable

The WEC plant should be highly reliable to avoid costly unplanned maintenance. High reliability is achieved with proven (Technology Class 1) high quality components, by minimizing the number of parts/components subject to well known failure modes (fatigue, wear, abrasion, corrosion, chemical attack, thermal overload, clogging, photolysis) and by avoiding impulsive loads (end-stops, shock loading, snap loads). Duration of repair for systems that may require unplanned maintenance (including waiting time between weather windows) should be short.

TRL1
In answering these questions consider the likelihood of UNPLANNED maintenance and the implications of this for AVAILABILITY. Consider the reduction in power generation capacity and the downtime due to failure,

maintenance and waiting/preparing for maintenance.

For the system(s) that Collect, Aggregate & Deliver Wave Power and the system(s) that Control Position:

- What is the target availability for the overall WEC plant?
- What is the technology class for each system in the WEC Plant?
- What are the expected weather window criteria for each maintenance event for each system?
- For each system that might require an intervention what is the expected location of the intervention? (factory, on-shore, dry-dock, quay-wall, harbor, in-shore, at-sea)
*No specific guidance on high medium and low, consider implications of answer on availability in context of other answers in this section.
e.g. for maintenance on-shore or at quay wall device must be removed from installation location, for maintenance in-shore or at-sea qualified workers must be transported to the device and must access it safely.*
- What is the size & mass of items being transported and maneuvered?
- How many systems have failure modes with consequent reduction in power production capabilities of >10% of total plant? (e.g. aggregation points, export cables, single points of significant loss of generation/export)
- Does the system have any redundancy in the aggregation points and power delivery system? (e.g. are there any other routes for the power to get to the grid?)

TRL3

Complete in addition to updating TRL1 and consider the same areas.

- What is the maximum array size (MW capacity) that can be serviced by one maintenance vessels (or team of vessels where multiple vessels are needed for a single intervention)?
- What is the technology class for each sub-system in the WEC Plant?
- What is the list of sub-systems that are likely to be subject to well known failure modes and which modes (e.g. fatigue, wear, abrasion, corrosion, chemical attack, thermal overload, clogging, photolysis, other...).

- For a full list of possible failures in systems and sub-systems what is:
 - a. The power capacity reduction consequence of each?
 - b. The anticipated total downtime?
 - c. The waiting time for spare parts?
 - d. The time required to repair each? (including access time)
 - e. The probability of occurrence of the failure.

Note: Refer to FMECA in answering these questions.

- How many systems where the failure rates are unknown or unverified in this application?
- What is the total anticipated number of unplanned maintenance events per MW per year and how will this change over the lifetime of the plant?
- For each sub-system that might require an intervention what is the location of the sub-system within the system and how modular and accessible is it?
- For each sub-system that might require an intervention what is the expected location of the intervention? (factory, on-shore, dry-dock, quay-wall, harbor, in-shore, at-sea)

*No specific guidance on high medium and low, consider implications of answer on **AVAILABILITY** in context of other answers in this section. e.g. for maintenance on-shore or at quay wall device must be removed from installation location, for maintenance in-shore or at-sea qualified workers must be transported to the device and must access it safely.*

- For the chosen vessel type(s) and typical/target installation location and required maintenance tasks what is the round trip travel time plus maintenance time for maintenance interventions?
- In the system that collects wave power what is the Length of conduit (e.g. cable/pressure-pipe) used per MW and number of terminations per MW?
- What is the availability and length of time to access spare parts?
- Are the weather window criteria primarily determined by the capabilities of the vessels or the dynamics of the device?
- Is it necessary for maintenance for personnel to transfer to the WEC at sea?

<ul style="list-style-type: none"> • Where personnel are required enter enclosed spaces in the WEC at sea for maintenance what is the duration required to ventilate the compartment before it is safe to enter? • Does the array layout allow for easy access for maintenance vessels?
TRL5
<ul style="list-style-type: none"> - For each mode of failure: - Number of failures over lifetime of plant (= component count * lifetime / MTBF) - Power capacity reduction as a consequence of failure - Duration of state with reduced capacity = max(mean waiting time between weather windows, procurement time of spare parts) + transportation time (for bringing maintenance team to system or bringing system back to facility) + Duration of repair

C1.4.2. Be durable over the lifetime of the plant

The WEC plant should be highly durable to avoid costly planned maintenance. The WEC plant is made of high durability (long lifetime) components, the number of parts/components subject to wear, abrasion and erosion is small. Ideally, the durability of plant's components, sub-systems, systems is the same as the lifetime of the plant. Time of repair for systems that require planned maintenance (including waiting time between weather windows) should be short.

TRL1
<p>In answering these questions consider PLANNED maintenance and the implications of this for AVAILABILITY. Consider the reduction in power generation capacity and the downtime due to maintenance and, if relevant, waiting/preparing for maintenance.</p> <p>For the system(s) that Collect, Aggregate & Deliver Wave Power and the system(s) that Control Position:</p> <ul style="list-style-type: none"> • What is the target availability for the overall WEC plant? • What is the technology class for each system in the WEC Plant? • How many systems have a MTBF < lifetime of the WEC Plant? • What are the expected weather window criteria for each maintenance event for each system?

<ul style="list-style-type: none"> • For each system that might require an intervention what is the expected location of the intervention? (factory, on-shore, dry-dock, quay-wall, harbor, in-shore, at-sea) <p><i>No specific guidance on high medium and low, consider implications of answer on AVAILABILITY in context of other answers in this section. e.g. for maintenance on-shore or at quay wall device must be removed from installation location, for maintenance in-shore or at-sea qualified workers must be transported to the device and must access it safely.</i></p> <ul style="list-style-type: none"> • What is the size & mass of items being transported and maneuvered? • How many systems have failure modes with consequent reduction in power production capabilities of >10% of total plant? (e.g. aggregation points, export cables, single points of significant loss of generation/export) • Does the system have any redundancy in the aggregation points and power delivery system? (e.g. are there any other routes for the power to get to the grid?)
<p>TRL3</p> <p>Complete in addition to TRL1 and consider the same areas.</p> <ul style="list-style-type: none"> • What is the maximum array size (MW capacity) that can be serviced by one maintenance vessels? • What is the technology class for each sub-system in the WEC Plant? • How many systems have a MTBF < lifetime of the Plant? • What is the number of systems that have manufacturer recommended services / inspections over the plant lifetime and how many inspections are required? • What is the total anticipated number of planned maintenance events per MW per year and how will this change over the lifetime of the plant? • For each sub-system that might require an intervention what is the

<p>location of the sub-system within the system and how modular or accessible is it?</p> <ul style="list-style-type: none"> For each sub-system that might require an intervention what is the expected location of the intervention? (factory, on-shore, dry-dock, quay-wall, harbor, in-shore, at-sea) <i>No specific guidance on high medium and low, consider implications of answer on AVAILABILITY in context of other answers in this section. e.g. for maintenance on-shore or at quay wall device must be removed from installation location, for maintenance in-shore or at-sea qualified workers must be transported to the device and must access it safely.</i> For the chosen vessel type(s) and typical/target installation location and required maintenance tasks what is the round trip travel time plus maintenance time for maintenance interventions? Are the weather window criteria primarily determined by the capabilities of the vessels or the dynamics of the device? Is it necessary, for maintenance for personnel to transfer to the WEC at sea? Where personnel are required enter enclosed spaces in the WEC at sea for maintenance what is the duration required to ventilate the compartment before it is safe to enter? Does the array layout allow for easy access for maintenance vessels?
<p>TRL5</p>
<p>For each mode of service:</p> <ul style="list-style-type: none"> - Number of service over lifetime of plant = number of components * plant lifetime / duration between services - Power capacity reduction - Duration of state with reduced capacity = max(mean waiting time between weather windows, procurement time of spare parts) + transportation time (for bringing maintenance team to system or bringing system back to facility) + Duration of service

C2. Provide a secure investment opportunity

For investors and financiers, it is critical that **WEC plant risks** are **well understood and manageable** so that they **know** the **financial risk**, i.e. the risk that the plant will **not deliver** the **expected** financial **return**. The financial risk results from the analysis of the probabilities of the risks and of their financial consequences. Uncertainties on costs (CAPEX, OPEX) and revenues (energy production, availability, survivability) are the drivers.

C2.1. Be survivable

Because of the stochastic nature of the plant environment (including other users of the area and grid) and uncertainties in the understanding of the response of the plant, events with probabilities beyond design conditions may happen. In these conditions, the damages may lead to loss of functions. The financial consequences of these damages shall be well understood and as limited as possible.

C2.1.1. Be able to survive extreme loads/responses

Because of the stochastic nature of the marine environment, weather conditions or operational conditions may lead to extreme loads and/or responses that exceed Ultimate Limit States (ULS) or Fatigue Limit States (FLS). The probabilities of such events and their financial consequences (repair costs, loss of assets or loss of production) shall be understood. If relevant, possible cascade failures shall be considered.

TRL1

- At plant level, how many systems may be significantly damaged by weather or operational conditions leading to loads and/or responses exceeding ULS or FLS?
 - a. If relevant, the plant shall be assumed to be in survival mode. In this case, describe the survival mode and the load shedding mechanisms.
- For each identified damage at plant level, what is the consequence class w.r.t loss of production, repair costs or loss of assets?
- At system level, what is the target safety level for all limit states?
- What is the size of the systems that collect wave power?
- How many stress concentration points are in the wave power collecting system (e.g heave plate connection on spar)?
- For the systems that collect wave power, how many sub-systems may be significantly damaged by weather or operational conditions leading to loads and/or responses exceeding ULS or FLS?

<ul style="list-style-type: none"> a. If relevant, the wave power collecting system shall be assumed to be in survival mode. In this case, describe the survival mode and the load shedding mechanisms. • For each identified damage in the wave power collecting systems, what is the consequence class w.r.t loss of production, repair costs or loss of assets? • For the system that aggregates the collected power, what is the dynamic of the point of connections?
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TRL3

<ul style="list-style-type: none"> • At plant level, how many sub-systems may be significantly damaged by weather or operational conditions leading to loads and/or responses exceeding ULS or FLS, including cascade failures? <ul style="list-style-type: none"> a. If relevant, the plant shall be assumed to be in survival mode. In this case, describe the survival mode and the load shedding mechanisms. • For each identified damage, what is the probability of occurrence and consequence class w.r.t loss of production, repair costs or loss of assets? • Could failures of some sub-systems lead to failures of other sub-systems or systems (cascade failure)? • For the systems that collect wave power, how many components may be significantly damaged by weather or operational conditions leading to loads and/or responses exceeding ULS or FLS? <ul style="list-style-type: none"> a. If relevant, the wave power collecting system shall be assumed to be in survival mode. In this case, describe the survival mode and the load shedding mechanisms. • For the systems that collect wave power, what are the target safety level (low, normal, high) and associated load factors for ULS, and FLS? • For each identified damage in the wave power collecting systems, what is the probability of occurrence and consequence class w.r.t loss of production, repair costs or loss of assets? <p>For the systems that aggregate & deliver the collected power, what are the target safety level (low, normal, high) and associated load factors for relevant loads for ULS, ALS and FLS?</p> <ul style="list-style-type: none"> • What is the number of sub-systems where loads are directly related to full distribution of incident energy vs. the number where loads are related to a

<p>truncated distribution i.e. are protected from the extreme tails of the distribution. (e.g. force is clipped to a known max value due to action of hydraulic relief valve)?</p> <p>a. Note: Consider all point loads, bearings, PTO, moorings, end stops, etc.</p>
TRL5
<ul style="list-style-type: none"> • What is the financial risk for the plant of weather or operational conditions leading to loads and/or responses exceeding ULS or FLS? <ul style="list-style-type: none"> a. As function of increasing return period for environmental conditions, list damages, cost of repair, loss of assets, loss of production • For the systems that collect wave power, aggregate power and deliver power, what are the risk rankings as a result of the PLS analysis? <ul style="list-style-type: none"> a. Provide distribution of relevant loads as function of increasing return period for environmental conditions. Relevant loads may include hydrodynamic loads, PTO loads, end-stop loads, mooring loads including snap loads, power saturation, thermal loads, point loads. Environmental conditions shall take into account biofouling and geophysical conditions.

C2.1.2. Be able to cope with grid failures, grid loss or grid interruption

The grid is an external system to the WEC's plant. Grid failure is a critical Ultimate Limit State (ULS). Technical and financial consequences of such an event shall be understood.

TRL1
<ul style="list-style-type: none"> • At plant level, how many systems may be significantly damaged by grid failure, grid loss or grid interruption? • For each identified damage at plant level, what is the consequence class w.r.t loss of production, repair costs or loss of assets? • For the systems that collect wave power, how many sub-systems may be significantly damaged by grid failure, loss of interruption? <ul style="list-style-type: none"> a. For each sub-system, if relevant, explain how power absorption is stopped, how excess power is dumped, how overheating and/or freewheeling is avoided. • For each identified damage of sub-systems in the wave power collecting systems, what is the consequence class w.r.t loss of production, repair costs or loss of assets?

<ul style="list-style-type: none"> For the systems that aggregate the collected power, are they able to reroute power from one source to other sources?
TRL3
<ul style="list-style-type: none"> At plant level, how many sub-systems may be significantly damaged by grid failure, loss or interruption? <ul style="list-style-type: none"> For each sub-system, if relevant, explain how excess power is dumped, how overheating is avoided, what are the protections against short cuts and over currents. For each identified damage, what is the probability of occurrence and consequence class w.r.t loss of production, repair costs or loss of assets? Are the systems of the plant internally powered? How long does it take to get back into power generation mode once grid is reestablished? For the systems that collect wave power, how many components may be significantly damaged by grid failure, loss or interruption? <ul style="list-style-type: none"> For each component, if relevant, explain how power absorption is stopped, how excess power is dumped, how overheating and/or freewheeling is avoided. For each identified damage of components in the wave power collecting systems, what is the probability of occurrence and consequence class w.r.t loss of production, repair costs or loss of assets?
TRL5
<ul style="list-style-type: none"> What is the financial risk for the plant of grid failures, grid losses or grid interruption? <ol style="list-style-type: none"> List induced damages if any, cost of repair of induced damages, loss of assets, loss of production

C2.1.3. Be able to avoid and survive to collisions

Other marine users, ships, marine mammals are external systems to the WEC plant. They may collide with one or several systems of the plant resulting in an Accidental Limit State (ALS). It may result in cascade failures. Technical and financial consequences of such events shall be understood.

TRL1
<ul style="list-style-type: none"> Where are the WEC plant systems in the water column? Can the WEC

<p>plant systems be easily detected?</p> <p>a. Provide list of means by which the WEC plant systems will signal to other users of the area and marine life.</p> <ul style="list-style-type: none"> • Taking into account mooring lines, cables, subsurface and surface floats, how packed is the WEC plant? • Are there many other human activities in the target deployment location? • Are there many marine mammals in the target deployment location? • How large is the typical watch-circle radius of the WEC plant systems? • How many WEC plant systems may be significantly damaged by collision with a ship? • For each of the identified damage, what is the consequence class of w.r.t loss of production, repair costs or loss of assets? • How many WEC plant systems may be significantly damaged by collision with a marine mammal? • For each of the identified damage, what is the consequence class of w.r.t loss of production, repair costs or loss of assets?
TRL3
<ul style="list-style-type: none"> • Can the WEC plant systems be easily detected? <ul style="list-style-type: none"> a. Provide list of means by which the WEC plant systems will signal to other users of the area and marine life. • Taking into account mooring lines, cables, subsurface and surface floats, how packed is the WEC plant? • How many WEC plant sub-systems may be significantly damaged by collision with a ship? • For each of the identified damage, what is the probability of occurrence and consequence class of w.r.t loss of production, repair costs or loss of assets? • How many WEC plant sub-systems may be significantly damaged by collision with a marine mammal? • For each of the identified damage, what is the probability of occurrence and consequence class of w.r.t loss of production, repair costs or loss of

assets?
TRL5
<ul style="list-style-type: none"> What is the financial risk for the plant of collision with ships, other users of the marine space and marine mammals? <ul style="list-style-type: none"> List possible collision scenario, probabilities of collisions, induced damages, cost of repair, loss of assets, loss of production

C2.1.4. Be survivable in temporary conditions (e.g. installation including tow-out if applicable or maintenance)

Because of the stochastic nature of the marine environment, weather conditions or operational conditions may lead to extreme loads and/or responses that exceed Serviceability Limit States (SLS) during temporary conditions. The probabilities of such events and their financial consequences shall be understood.

TRL1
<ul style="list-style-type: none"> What is the distance from shore? What is the size of the systems to install or maintain? How different is their orientation in temporary conditions vs in operations?
TRL3
<ul style="list-style-type: none"> How long does it take to tow-out the systems to install? How long does it take to install? How long does it take to maintain? How different is their orientation in temporary conditions vs in operations? Can operations carried out in temporary conditions be easily interrupted? At plant level, how many sub-systems may be significantly damaged by weather or operational conditions leading to loads and/or responses exceeding ULS during temporary conditions, including cascade failures? <ul style="list-style-type: none"> Provide distribution of relevant loads as function of increasing environmental conditions. Relevant loads may include hydrodynamic loads, snap loads in towing lines, point loads,

<p>bending in electrical cables.</p> <ul style="list-style-type: none"> • For the sub-systems that may be significantly damaged, what are the target safety level (low, normal, high) and associated load factors?
TRL5
<ul style="list-style-type: none"> • What is the financial risk for the plant of weather or operational conditions leading to loads and/or responses exceeding ULS during temporary conditions? <ul style="list-style-type: none"> a. As function of increasing environmental conditions, list damages, cost of repair, loss of assets, loss of production or delay in first power.

C2.2. Be low risk under design conditions

For investors and financiers, it is critical that **WEC plant risks** are **well understood and manageable** so that they **know** the **financial risk**, i.e the risk that the plant will **not deliver** the **expected** financial **return**. The financial risk results from the analysis of the probabilities of the risks below and of their financial consequences. Uncertainties on costs (CAPEX, OPEX) and revenues (energy production, availability, survivability) are the drivers.

C2.2.1. Be low uncertainty on OPEX

OPEX may be greater than expected because of reliability and/or durability issues. It is important that components and sub-systems have been qualified for their use in the context of the wave energy plant. Standard deviations and uncertainties on the MTBF of those components and sub-systems may be used to assess the risk on OPEX.

TRL1
<ul style="list-style-type: none"> • What percentage of the overall plant is comprised of technology class 3 or 4 systems (mechanisms that collect wave power, aggregate power, deliver power, and control position)? • What are the well known failure modes (shocks, chemical, corrosion, wear, fatigue, thermal, etc.) for each system? • What are the well know failure modes for the subsystems (structure, power-take off, etc.) within the system collect wave power? • For the identified maintenance weather windows, what is the target duration of the weather window? With what frequency are these conditions to be expected over a year?

TRL3

Update the answers to TRL1 plus answer the following questions:

- Within each system, what are the percentages of Technology Class 3 or 4 sub-systems and components?
- When addressing the failure modes for each system, additionally address for each sub-system within the system. Also, please utilize the following questions to guide more detailed answers (i.e. identify the different modes of failure: fatigue, wear, abrasion, corrosion, chemical attack, thermal overload, clogging, photolysis, other).
 - a. Has fatigue analysis been performed and alterations made to the sub-systems to account for repeated cycles over the lifetime of the plant?
 - b. What type of biofouling (flora and fauna types) is expected and on which sub-systems?
 - e. What level of corrosion is expected and what steps were taken to account for corrosion on each relevant sub-system?
 - i. If applicable, has the conductance between dissimilar metal types contacting sea water been quantified / mitigated?
 - c. Which sub-systems are thermally sensitive and what mitigation steps have been taken?
 - d. Which sub-systems have sensitivities to chemical degradation and what steps have been taken to address these sensitivities (batteries, lubricating oil, electrolytic capacitors, etc.)?
 - e. Which sub-systems are sensitive to acceleration or orientation and what mitigation steps have been taken?
 - f. Which sub-systems are directly subject to the full distribution of incident energy? Which sub-systems are subject to a subset of the distribution (aka peak load is a known value)?
- Within each system, what are the mean time between failures (MTBF) and the standard deviations on the MTBFs for each sub-system and component?
- What is the risk ranking for each sub-system within each system? The risk ranking is a quantitative procedure which ranks failure modes according to their probability and consequences (i.e. the resulting effect of the failure mode on safety, environment, operation and asset). The probability classes, consequence classes, and risk ranking are detailed in the definitions.
- For the identified sea conditions maintenance thresholds, please answer the following questions using a minimum of 10 years of data (design class from PT62600-101):
 - a. What is the average frequency and standard deviation of that frequency within each month that the identified continuous duration

<p>within the weather window that is needed for maintenance?</p> <ul style="list-style-type: none"> b. Have the maintenance thresholds taken into account the ensuing dynamics of the systems? If yes, please explain how they have been accounted for. c. What is the criticality if a maintenance task must be stopped before completed (use risk ranking identified above)? d. If applicable, at what sea condition threshold will the hydrostatic stability of disconnected systems become compromised? <ul style="list-style-type: none"> • When determining the durations required for each maintenance activity, were the dynamics of the system or sub-system taken into account? Do the durations appropriately account for multi-stepped activities? • In addition to the physical conditions at sea, other factors like overtime hours, safety training, etc. will influence the cost of maintenance—these define the permit window. What are these factors for this deployment location and what regulatory mandates supervise the workforce? • What is the sensitivity of the maintenance vessel(s) cost to external factors (e.g. activity in oil & gas exploration)? How many competing suppliers of maintenance vessel(s) are there? • Has the speed that the maintenance vessel operates at been optimized?
TRL5
<ul style="list-style-type: none"> • Standard deviation of AA of cost of planned maintenance (standard deviation of MTBF, distribution of weather windows, number of Technology class 1 components/sub-systems/systems, number of failures*criticality of failures) • STD of AA of cost of planned maintenance shall result from a Monte Carlo analysis • What are the Design Fatigue Factors for all sub-systems? The DFF depends on the risk associated with a component/sub-system and on its accessibility and reparability. Risk in this case includes: human life, environment, operations and assets. However, weighting should be given to assets, since OPEX focus is on cost. <ul style="list-style-type: none"> a. What is the number of cycles before failure from the fatigue analysis? How do the cycles translate to the lifetime? • What are the load factors for the ULS for all sub-systems? <ul style="list-style-type: none"> a. How have the characteristic loads been validated (experimentally) or otherwise verified as applicable? • What is the risk ranking for each sub-system within each system? The

risk ranking is a quantitative procedure which ranks failure modes according to their probability and consequences (i.e. the resulting effect of the failure mode on safety, environment, operation and asset). The probability classes, consequence classes, and risk ranking are detailed in the definitions.

C2.2.2. Be low uncertainty on availability

Availability may be smaller than expected because of uncertainties in the reliability and/or the durability of components and sub-systems. With unplanned maintenance activities being more frequent than expected, the plant availability is smaller than expected. Availability may also be smaller because waiting time between weather windows for planned and unplanned maintenance is longer than expected.

TRL1
<ul style="list-style-type: none"> • What percentage of the overall plant is comprised of Technology Class 3 or 4 systems (mechanisms that collect wave power, aggregate power, deliver power, and control position)? • What are the well known failure modes (shock, chemical, corrosion, wear, fatigue, thermal, etc.) for each system? • What are the well known failure modes for the subsystems (structure, power-take off, etc.) within the system collect wave power? • For the identified maintenance weather windows, what is the target continuous duration of the weather window? With what frequency are these conditions to be expected over a year?
TRL3
<p>Update the answers to TRL1 plus answer the following questions:</p> <ul style="list-style-type: none"> • Within each system, what are the percentages of Technology Class 3 or 4 sub-systems and components? • When addressing the failure modes for each system, additionally address for each sub-system within the system. Also, please utilize the following questions to guide more detailed answers: <ol style="list-style-type: none"> a. Has fatigue analysis been performed and alterations made to the sub-systems to account for repeated cycles over the lifetime of the plant? b. What type of biofouling (flora and fauna types) is expected and on which sub-systems? c. What level of corrosion is expected and what steps were taken to account for corrosion on each relevant sub-system?

- i. If applicable, has the conductance between dissimilar metal types contacting sea water been quantified / mitigated?
 - d. Which sub-systems are thermally sensitive and what mitigation steps have been taken?
 - e. Which sub-systems have sensitivities to chemical degradation and what steps have been taken to address these sensitivities (batteries, lubricating oil, electrolytic capacitors, etc.)?
 - f. Which sub-systems are sensitive to acceleration or orientation and what mitigation steps have been taken?
 - g. Which sub-systems are directly subject to the full distribution of incident energy? Which sub-systems are subject to a subset of the distribution (aka peak load is a known value)?
- Within each system, what are the mean time between failures (MTBF) and the standard deviations on the MTBFs for each sub-system and component?
- What is the risk ranking for each sub-system within each system? The risk ranking is a quantitative procedure which ranks failure modes according to their probability and consequences (i.e. the resulting effect of the failure mode on safety, environment, operation and asset). The probability classes, consequence classes, and risk ranking are detailed in the definitions.
 - a. Has any redundancy been added to alter the risk ranking? If so, please identify the system, sub-system, component that was made redundant.
- For the identified sea conditions maintenance thresholds, please answer the following questions using a minimum of 10 years of data (design class from PT62600-103):
 - a. What is the average frequency and standard deviation of that frequency within each month that the identified continuous duration below the threshold that is needed for maintenance?
 - b. Have the maintenance thresholds taken into account the ensuing dynamics of the systems? If yes, please explain how they have been accounted for.
 - c. What is the criticality if a maintenance task must be stopped before completed (use risk ranking identified above)?
 - d. If applicable, at what sea condition threshold will the hydrostatic stability of disconnected systems become compromised?
- When determining the durations required for each maintenance activity, were the dynamics of the system or sub-system taken into account? Do the durations appropriately account for multi-stepped activities?
- In addition to the physical conditions at sea, other factors like overtime

<p>hours, safety training, etc. will influence the cost of maintenance. What are these factors for this deployment location and what regulatory mandates supervise the workforce?</p> <ul style="list-style-type: none"> • Has the speed that the maintenance vessel operates at been optimized?
TRL5
<ul style="list-style-type: none"> • What is the standard deviation on the on power capacity reduction? <ul style="list-style-type: none"> a. Monte Carlo analysis should be performed using 10 years of sea state data to determine this value. • What is the standard deviation on the duration of state with reduced capacity? <ul style="list-style-type: none"> a. Monte Carlo analysis should be performed using 10 years of sea state data to determine this value. • What are the Design Fatigue Factors for all sub-systems? The DFF depends on the risk associated with a component/sub-system and on its accessibility and reparability. Risk in this case includes: human life, environment, operations and assets. However, weighting should be given to operations, since availability focus is on duration. • For the temporary load cases occurring during transportation, installation, uninstallation, and maintenance what load factors and characteristics loads have been determined?

C2.2.3. Be low uncertainty on energy production

Energy production may be smaller than expected because the resource may be smaller than expected. Energy production estimates are normally made based on the statistically worst year. First power may be delayed because of acceptability issues, or delays in construction. It may be mitigated through insurances or penalties in contracts with suppliers.

TRL1
<ul style="list-style-type: none"> • For the identified target wave resource, what is the typical yearly energy variability over the region where the system that collects wave power is expected to operate? • What aspects of the system that collects wave power are expected to decrease energy production (e.g. end stops, sharp edges producing large viscous losses, power conversion chain that is intended to work at one speed only, long transition times between operational states, etc.)? • May the technology be a concern for the local communities that could cause delays in first power production?

TRL3
<p>Update the answers to TRL1 plus answer the following questions:</p> <ul style="list-style-type: none"> • What are the validation results for the numerical model? Specify the aspects that have been validated (direction, array interaction, control, etc.). • What is the average annual power production at PoC for the statistically most energetic year (95th percentile year) and what is the average annual power production at PoC in the statistically least energetic year (5th percentile year) (using a minimum of 10 years of data as requested in Design Class PT62600-101)? • What steps have been taken to mitigate delays in first power production (environmental / societal impact from the WEC Plant)?
TRL5
<ul style="list-style-type: none"> • What is the standard deviation of average annual power production at PoC over the 10 year period? What is the worst average annual power production at PoC? What is the best average annual power production at PoC? • What are the LCOEs for the WEC Plant given the variation from worst to average to best average annual power productions at PoC? • How much contingency has been built into the construction and installation schedules?

C2.2.4. Be low uncertainty on CAPEX

CAPEX may be greater than expected. It may happen because of increase in materials and/or components prices; and/or increased manufacturing costs/durations; and/or increased transportation and installation costs. The supply chain should be low risk.

TRL1
<ul style="list-style-type: none"> • What percentage of the WEC Plant will be comprised of Technology Class 3 or 4 systems (mechanisms that collect wave power, aggregate power, deliver power, and control position)? • What material types in the WEC Plant, if any, are rare or located only in particular parts of the world; i.e. what material types are vulnerable to price fluctuations? • Are new manufacturing facilities / workforce expertise needed to construct systems within the WEC Plant?

TRL3
<p>Update the answers to TRL1 plus answer the following questions:</p> <ul style="list-style-type: none"> • For the identified installation thresholds on the sea conditions, please answer the following questions using a minimum of 10 years of data (design class from PT62600-103): <ul style="list-style-type: none"> a. What is the average frequency and standard deviation of that frequency within each month that the identified continuous duration below the threshold that is needed for installation? b. Have the installation thresholds taken into account the ensuing dynamics of the systems? If yes, please explain how they have been accounted for. c. What is the criticality if an installation task must be stopped before completed (use risk ranking identified above)? d. If applicable, at what sea condition threshold will the hydrostatic stability of disconnected systems become compromised? • When determining the durations required for each installation activity, were the dynamics of the system(s) or sub-system(s) taken into account? Do the durations appropriately account for multi-stepped activities? • Will any non-standard transportation be required (e.g. escort for oversized load, construction of new infrastructure, etc.)? Identify the type and the effect this is expected to have. • Will components be sourced from large reputable companies with long standing histories?
TRL5
<ul style="list-style-type: none"> • What are the standard deviations on the following projections: expected manufacturing rate in day / MW and MW's of installed power per year. • If applicable, have CAPEX projections included inflation to account for a phased construction and installation schedule? • What percentage of contingency has been added to the CAPEX projections?

C3.Be reliable for grid operations

Reliability for grid operations covers several aspects. The **energy production** from the WEC plant **must be predictable** sufficiently in advance **to enter the day-ahead wholesale electricity market**. Moreover, the increase of the share of **intermittent renewable energy sources** in the energy mix **is challenging for grid** operators w.r.t grid stability and load balancing. It could limit the deployment potential of wave energy. Thus, **energy production**

from the WEC plant **needs to be sufficiently consistent** (short term variability) and WEC plant needs to have a **high capacity factor**. Moreover, a WEC plant shall **provide useful ancillary services** to the grid. They include energy storage, automatic generation control (AGC), voltage and frequency control.

C3.1. Be forecastable

The **electricity market requires prediction of the energy production in advance**, thus the energy production from the WEC plant must be predictable. Typical time scale for prediction is in the range from half an hour to a day ahead.

TRL1
<ul style="list-style-type: none"> Has the WEC plant particular features that make it less likely to be forecastable than WEC plant with other technologies?
TRL3
<ul style="list-style-type: none"> How robust is energy production to errors in wave resource prediction?
TRL5
<ul style="list-style-type: none"> What is the uncertainty on power production as function of the prediction horizon (including how uncertainty in the resource prediction affects power production prediction)? <ul style="list-style-type: none"> Focus on 20' to 24h prediction horizon, driven by requirements to enter the electricity market.

C3.2. Have stable annual power production

Long term variability (time scale > hour) is an issue for the grid operator in the **planning of future energy capacities** and reserves. Grid operator prefers power sources that can contribute to base load. High **capacity factor**, defined as the ratio of the plant output over a year to its potential output if it were operating continuously at full nameplate capacity, indicates low long term variability.

TRL1
<ul style="list-style-type: none"> What is the target capacity factor?
TRL3
<ul style="list-style-type: none"> What is the net capacity factor of the WEC plant? <ul style="list-style-type: none"> Provide annual average for the power production at point of connection to the grid according to C1.3 Provide WEC plant rated power at point of connection to the grid. Provide availability according to C1.4

TRL5
<ul style="list-style-type: none"> • What is net the capacity factor of the WEC plant? <ul style="list-style-type: none"> a. Provide average for the power production at point of connection to the grid according to C1.3 b. Provide WEC plant rated power at point of connection to the grid. c. Provide availability according to C1.4

C3.3. Be useful to the grid

The integration of **intermittent renewable energy sources** is **challenging for grid operators** w.r.t grid stability and load balancing. The WEC plant **shall provide useful ancillary services** to the grid. They include energy storage, automatic generation control (AGC), voltage and frequency control, operational reserves.

TRL1
<ul style="list-style-type: none"> • Has the WEC plant significant energy storage that can be used to provide ancillary services to the grid?
TRL3
<ul style="list-style-type: none"> • How much and for how much time can reactive power be absorbed by the WEC plant at point of connection to the grid? • How much and for how much time can extra power can be provided to the grid? • Is the plant able to blackstart? • Can the output power be capped for curtailment purposes?
TRL5
<ul style="list-style-type: none"> • How much and for how much time can reactive power be absorbed by the WEC plant at point of connection to the grid? <ul style="list-style-type: none"> a. Provide figures of reactive power that can be absorbed as function of time and ramp-up time. • How much and for how much time can extra power can be provided to the grid? <ul style="list-style-type: none"> a. Provide figures of extra power that can be provided as function of time and ramp-up time. • How much and for how much time output power can be capped for curtailment purposes?

C4.Be beneficial to society

A **WEC plant needs** to obtain **buy-in and support** from the local communities and the general public. Indeed, as any industrial project, a **WEC plant** will **have some negative impacts** (higher cost of energy, disruption to other activities) **that needs to be largely overcome by benefits for society** (low carbon emission energy source, local jobs creation, coastal protection). Otherwise, public concerns and actions against the project can seriously delay the project or make it fail (even if permits are granted).

C4.1. Be beneficial to local communities

The WEC plant needs to be beneficial to local communities to obtain buy-in and support from them. Local benefits includes **local job creation, increase of local GDP, protection from coastal erosion.**

TRL1
<ul style="list-style-type: none">• How will the plant contribute jobs to the local community?
TRL3
Update the answers to TRL1 plus answer the following questions: <ul style="list-style-type: none">• Will components of the plant be manufactured near the deployment location?• Will installation and maintenance activities employ local ship owners?• What other local jobs will result due to the plants development?• Will local infrastructure be improved by the development of the plant; e.g., infrastructural upgrade of roads, harbors, communications, grid, etc.?• What ancillary benefits for the local community will the plant perform (such as coastal erosion protection, tourist draw, fish nursery, etc.)?
TRL5
<ul style="list-style-type: none">• What number of local jobs will be created in the following areas as a result of the plant's deployment in an area:<ul style="list-style-type: none">a. Construction (manufacturing and assembly of portions of the plant)?b. Installation and maintenance?c. Control center operation?d. Outreach and marketing?e. Legal?• What is the estimated tax revenue for the local community that this plant will produce?• What is the cost-savings or revenue generation that results from the identified ancillary benefits?

C4.2. Be low greenhouse gas (GHG) emission energy source

The WEC plant needs to be a **low GHG emission energy source** over the entire life cycle. A measure of life-cycle GHG emissions is the global warming potential per unit of electrical energy generated. The **global warming potential** is the ability of a GHG to **trap heat in the atmosphere relative to an equal amount of carbon dioxide** and is dependent upon a full life-cycle assessment.

TRL1
<ul style="list-style-type: none">• For each lifecycle stage, when will GHGs be released?
TRL3
<ul style="list-style-type: none">• What system boundaries will be used to determine the global warming potential?• What are the upstream (raw materials, construction, and installation) GHG emissions?• What are the operations (including maintenance) GHG emissions?• What are the downstream (decommissioning, disposal, and recycling) GHG emissions?
TRL5
<ul style="list-style-type: none">• What is the global warming potential of this plant in grams of carbon dioxide equivalent per kilowatt hour (gCO₂eq/kWh)?• What lifecycle stage is the largest contributor to the global warming potential?

C4.3. Be a low polluting energy source

The **entire lifecycle** needs to be considered for this capability.

TRL1
<ul style="list-style-type: none">• Are the WEC plant systems easily recyclable?• What is the lifetime of the WEC plant?
TRL3
<ul style="list-style-type: none">• Do the WEC plant manufacturing process and operation involve significant amount of pollutants (solids, liquids, gases)?• Are the WEC plant systems and sub-systems easily recyclable?

<ul style="list-style-type: none"> • How many times will the systems and sub-systems of the WEC plant need to be replaced to achieve the lifetime of the plant?
TRL5
<ul style="list-style-type: none"> • What are the pollutants involved in making and operating the WEC plant and in what amounts? • What are the sub-systems and components of the WEC plant that cannot be recycled and in what numbers? • How many times the sub-systems and components of the WEC plant need to be replaced to achieve the lifetime of the plant?

C4.4. Minimize impact on taxpayers

Electricity consumers are the final users of the generated electricity. They want **market competitive electricity** in the long term. The initial roll out of wave energy (e.g TPL7) will be at high cost of energy, it is vital to improve cost of energy after this initial deployment. Key question is: if a technology achieves TPL7, does evidence exist that the TPL can increase to TPL8 and 9 subsequently? What are the technical reasons to believe that it is possible? What are the expected learning rates?

TRL1
<ul style="list-style-type: none"> • What is the target TPL of the WEC plant?
TRL3
<ul style="list-style-type: none"> • What is the TPL of the WEC plant? • What is the target learning rate? <ul style="list-style-type: none"> ○ Provide justifications and explanations for how the target learning rate will be achieved with increasing number of installed MWs.
TRL5
<ul style="list-style-type: none"> • What is the cost difference between cost of energy of the WEC plant and market price? • What is the target learning rate? <ul style="list-style-type: none"> ○ Provide justifications and explanations for how the target learning rate will be achieved with increasing number of installed MWs.

C5.Be acceptable for permitting and certification

Permits for occupying the sea space and connecting to the grid **must be obtained by the WEC plant developer before building the WEC plant** (not having the permits is a **critical risk** for the plant developer, the investors and the financiers). Consequently, the WEC plant must **fulfill all regulatory and permitting requirements**. The requirements usually consist of assessing and addressing environmental impacts, impacts to other users of the area and impacts to the electrical grid.

C5.1. Be environmentally acceptable

The WEC plant technology and design must enable the construction of a power plant that meets all environmental regulations. Thus, it must cause **no unacceptable impacts on the seafloor; no unacceptable impacts on local currents or sedimentation; no unacceptable impacts on local or global wildlife; no unacceptable impacts on local or global plant life.**

TRL1
<ul style="list-style-type: none"> • What environmental sensitives are at the proposed location (e.g. endangered and threatened species, migratory routes, large shifts in sediments, etc.)? • Will the plant generate any output (noise, effluent, etc.) that would affect the environment?
TRL3
<ul style="list-style-type: none"> • What are the information needs and specific studies needed to ensure an acceptable deployment for all of the environmental concern areas listed below: <ul style="list-style-type: none"> a. Species under special protection (Endangered Species act or other relevant international regulation)? b. Marine mammals (Marine Mammal Protection Act or other relevant international regulation)? c. Migratory Birds (Migratory Bird Threat Act (international treaty) or other relevant international regulation)? d. Important fish and shellfish populations (Magnuson Stevens Fishery Conservation Management Act or other relevant international regulation)? e. Habitats (Magnuson Stevens Fishery Conservation Management Act plus other federal and state regulations or other relevant international regulation)? f. Water Quality (Clean Water Act or other relevant international regulation)? • What studies have been completed to quantify impacts to the following: <ul style="list-style-type: none"> a. Impact of plant on coastal wave energy / sedimentation processes? b. Acoustic noise generation? c. Benthic ecosystems and invertebrates?

<ul style="list-style-type: none"> What additional monitoring will be required to ensure environmental acceptability?
TRL5
<ul style="list-style-type: none"> What regulatory applications have been submitted?

C5.2. Be acceptable to other users of the area

The WEC power plant technology and design must **integrate smoothly with other users of the area**. Other users of the area are local and global fishing industries, other industries using the local area, recreational users of the local area, tourists and entertainment uses of the local area, local communities.

TRL1
<ul style="list-style-type: none"> Who are the other users at the proposed location (e.g. dedicated fishing area, surfers, shipping route, sailing area, etc.)? What is the proposed size of the plant boundaries?
TRL3
<ul style="list-style-type: none"> What portions of the plant boundaries intersect with or will change the way other users interact with the sea space? What steps have been taken to ensure acceptability to these other typical/representative users? Social science research should be undertaken to gauge opinions and receptiveness.
TRL5
<ul style="list-style-type: none"> How many informational meetings have been held with each identified other typical/representative user and what were the outcomes?

C5.3. Be grid compliant

The WEC power plant must be capable of delivering electrical power that **meets grid operator requirements for power quality** (voltage, frequency, flicker).

TRL1
<ul style="list-style-type: none"> What is the typical size, MW rating, of the grid that the WEC Plant will be connected to? What is the target rating of the plant at grid point of connection (PoC)?
TRL3
<ul style="list-style-type: none"> Answer the following questions regarding the grid that will host a typical WEC Plant: <ol style="list-style-type: none"> What is the voltage at the point of common coupling (PCC)? What is the short-circuit level [4]?

<p>c. What is the impedance angle [4]?</p> <ul style="list-style-type: none"> • What equipment will specifically address flicker (e.g. storage or control strategies)? • What equipment will specifically address frequency? • What is the standard deviation of the peak to average electrical power production obtained from analysis of the full scatter diagram?
TRL5
<ul style="list-style-type: none"> • What electrical certifications have been obtained? • What is the flicker level at the PCC (calculated using IEC standards 61000-4-15 and 61400-21)? Is this level allowed within the local jurisdiction?

C6.Be acceptable w.r.t safety

Safety is a key requirement for any structure at sea. The WEC power plant must be safe for construction, installation, commissioning, operations, and decommissioning in order to meet all other capabilities.

TRL1
<ul style="list-style-type: none"> • Has a safety philosophy been incorporated into the design process? • Is there a threat to human health and safety during any of the life cycle stages? (Consider all life stages from design, manufacturing, assembly, lifting, transport, installation, operation, maintenance, removal, decommissioning etc.) • What is the target maximum safe sea state for O&M? • Does the design require personnel to transfer from a ship to the device at sea? • Does the design require personnel to enter enclosed spaces at sea? • Does the design require personnel to work in or under the sea? • Is any lifting done at sea?
TRL3

- Does the WEC technology have features that could be challenging with respect to safety compliance with relevant legislation in the applicable jurisdiction(s)? (e.g. Insert USA example, European directives on safety and health at work, UK “health and safety at work act”, UK “Construction Design Management regulations”)
- Has a hazard identification and risk assessment process been implemented for key activities in each life cycle stage?
 - a. Please provide the risk assessments for all the key activities in manufacture, installation, transport and O&M.
- What are the possible accidental states that have been identified? What measures are in the design to prevent / mitigate the increased probability of injury to personnel during accidental states?
- What are the possible temporary states that have been identified? What are the measures in the design to prevent / mitigate the increased probability of injury to personnel during temporary states?
- What is the number of vessels required simultaneously for each O&M activity?
- What are the measures in the design to prevent / mitigate collisions?

Note: Consider ships colliding with system in normal state e.g. at the farm location or systems in failed state colliding with ships e.g. outside the farm location. Ships colliding with each other should also be considered.
- Is the WEC plant and system(s) easily identifiable for vessels and sea users? E.g. navigational aids, lights, radar beacons etc.
- What is the number of remotely controlled operations vs onsite operations?
- What is the number of remotely monitored sensors vs onsite inspections?
- What are the arrangements for escape from the device at sea?
- Is specialist training of personnel required? E.g. Are any specialist tools required?
- Is there a risk of fire while people are onboard? Is there need for a detection and suppression system?

<ul style="list-style-type: none"> • Does the design require long periods of skilled maintenance? E.g. is the impact of workers' fatigue a consideration? • Is there a risk of contact with dangerous chemicals or liquids? • What is the number of connections that involve hands on human work at sea? E.g. connecting moorings or connecting crane hooks.
TRL5
<ul style="list-style-type: none"> • Is the approach to safety compliant with relevant legislation in the applicable jurisdiction(s)? (e.g. Insert USA example, European directives on safety and health at work, UK "health and safety at work act", UK "Construction Design Management regulations") • Number of injuries and fatalities over the lifetime of the plant that can be attributed to the WEC plant

C7.Be deployable globally

The ability to provide steady sales is another **key requirement for sustainable business for the WEC plant developer, construction company, and for the suppliers of the supply chain**. It may also be an important requirement for the **local-regional-national development agencies, policy makers and general society w.r.t to the overall benefits**. Thus, the WEC plant shall be deployable at many different sites, that represent a large global market share and be adaptable to variable site characteristics (wave resource, geophysical conditions, distance to shore, local infrastructure, ...)

TRL1
<ul style="list-style-type: none"> • What is the water depth requirement to deploy the WEC plant? • What is the target wave resource for attractive LCOE?
TRL3
<ul style="list-style-type: none"> • What is the global capacity of the WEC plant (estimated size of the resource that can be exploited by the WEC plant taking into account wave resource, water depth and geophysical conditions)? • Are the manufacturing and construction techniques / infrastructure able to be developed easily at many locations?
TRL5
<ul style="list-style-type: none"> • What is the global capacity of the WEC plant (size of the resource that

can be exploited by the WEC plant)?

- a. Provide map of suitable locations taking into account wave resource, water depth and necessary infrastructure.
- Are the manufacturing and construction techniques / infrastructure able to be developed easily at many locations?

GLOSSARY

Environment: includes the entirety of the ocean; sea conditions, other users, biologic and chemical factors, etc.

Sea Conditions: includes the 3-D spectral properties of the waves (frequency, direction, energy) as well as the tidal, current, and wind conditions.

Systems: larger scale implementations of higher level functions; WEC units, sub-station, electrical cable and connection to grid, and mooring systems.

Sub-systems: the sub-implementations of units that comprise a single system; WEC unit: primary absorber, structural support, PTO, and power electronics.

Components: the constituent entities that make the sub-systems; PTO: hydraulic rams, hydraulic motor, etc.

Equipment: when refer to maintenance components, the crane needed to achieve the maintenance—more like tools.

WEC: the system that collects wave power.

Collect wave power: The system that intercepts the incoming hydrokinetic power in the ocean resulting in kinetic motion and finally into transportable power

Aggregate wave power: The system that combines the collected wave energy before delivering the transportable power to the electrical delivery system.

Deliver electrical power: The system that generates electricity and conveys the electricity to the continental electrical grid.

Control position: The system that is capable of controlling the position and orientation of systems within the WEC power plant (i.e. potentially the sources used to capture wave power or to aggregate this power).

Net capacity factor: Gross capacity factor x availability

WEC plant rated power: maximum 15' average power exportable to the grid as agreed between the plant operator and the plant operator

Reliability: the likelihood that a system, sub-system or component will not fail within a given time period. Reliability is concerned with unplanned maintenance and random failures.

Durability: the length of a system, sub-system or components life. Durability is concerned with scheduled maintenance and planned maintenance activities especially where sub-systems and components have a shorter life than the plant at a whole.

MTBF: Mean time between failures.

Weather Windows: Periods of time where access is possible due to environmental variables being below relevant thresholds. E.g. waves, wind, current and tide.

Permit Windows: Periods of time where access is possible due to environmental variables, and any other variables, being below relevant thresholds. E.g. working hours limitations (legal or technical)

FMECA: Failures mode, effects and criticality analysis. FMECA methodology is further described in BS 5760, Part 5, Guide to failure modes, effects and criticality analysis and IEC-60300-9, Part 3: Application guide - Section 9: Risk analysis of technological systems.

Black Start: can start generating even if the grid isn't present (could also be a grid ancillary benefit)

Availability: the real capacity available to generate as a percentage of the rated or installed capacity (usually averaged over a year)

Capture Width: Ratio of mechanical power absorbed by a wave power collecting system to the incident wave energy flux. In meters

Limit State: A limit state is a condition beyond which a structure or structural component or system will no longer satisfy the design requirements. The following limit states are considered in order to satisfy, to a certain probability, that structure or system will fulfil its function:

- Ultimate limit states (ULS): corresponding to the maximum load-carrying resistance
- Fatigue limit states (FLS): corresponding to failure due to the effect of cyclic loading
- Accidental limit states (ALS) (including progressive collapse limit state - PLS): corresponding to survival conditions in a damaged condition or in the presence of nonlinear environmental conditions
- Serviceability limit states (SLS): corresponding to tolerance criteria applicable to intended use.

Accidental limit states with a probability of occurrence of less than 10^{-3} per year and involving only one system or unit may be considered as an SLS depending on the level of risk. In the case that the risk is not acceptable due to safety, environmental, economic or reputational viewpoint, the structural integrity should be improved. Accidental limit states involving progressive failure or failure with high economical or societal impact shall always be considered.

Target safety level: target safety level is a nominal acceptable probability of structural / system failure. The target safety level is described considering the definition of safety classes.

Safety Classes: Three safety classes (low, normal and high) are normally identified. Low safety class is defined where failure implies negligible risk to human life, low risk for personal injuries and pollution and low risk for economic consequences. Normal safety class defined where failure implies some risk for personal injuries, significant pollution or high economic or political consequences. High safety class defined where failure implies large possibilities for personal injuries or fatalities, significant pollution or very large economic or political consequences.

From experience with representative industries and activities the nominal annual probability of failure for the safety classes defined below:

- low safety class $<10^{-3}$ per annum
- normal safety class $<10^{-4}$ per annum
- high safety class $<10^{-5}$ per annum.

Safety classes may be considered while defining redundancy or safety features for the equipment and systems. Higher levels of safety may be required for critical sub-systems and components depending on their consequences of failure. As an example, due to access difficulties for unplanned maintenance (plus costs related to offshore intervention, and any additional “downtime” penalties when not generating to the grid), a higher level of reliability may be required.

Hence, safety aspect impacts all service and operational requirements resulting from the use of the device and the environmental conditions that can affect the design.

The normal safety level is aimed at for structures / systems, whose failures are ductile, and which have some reserve capacity.

The target safety levels for the different systems and components should be identified in the risk assessment stage taking into account the present constraints regarding access and aimed reliability. The normal safety level is aimed and it is reflected in the use of existing standards from other industries and adjusted requirements to address novelty and risks.

Risk: the qualitative or quantitative likelihood of an accident or unplanned event occurring, considered in conjunction with the potential consequences of such a failure. In quantitative terms, risk is the quantified probability of a defined failure mode multiplied by its quantified consequences.

Risk Matrix: defines the risk level (low, medium and high for example) for each combination of the different probability and consequence classes.

Probability	Consequence				
	1	2	3	4	5
5	Low	Med	High	High	High
4	Low	Med	Med	High	High
3	Low	Low	Med	Med	High
2	Low	Low	Low	Med	Med
1	Low	Low	Low	Low	Med
Notes:					
Low	Tolerable, no action required				
Medium	Mitigation and improvement required to reduce risk to Low				
High	Not acceptable: mitigation and improvement required to reduce risk to Low (ALARP)				

Probability Classes: defines the different probability levels that can be expected for an event to occur. It is normally associated to a failure mechanism that it is triggered by an event. The probability is classified from the very frequent to the remote / accidental event.

Class	Name	Description	Indicative annual failure rate (up to)	Reference
1	Very Low	Negligible event frequency	1.0E-04	Accidental (event not failure)
2	Low	Event unlikely to occur	1.0E-03	Strength / ULS
3	Medium	Event rarely expected to occur	1.0E-02	Fatigue / FLS
4	High	One or several events expected to occur during the lifetime	1.0E-01	Operation low frequency
5	Very high	One or several events expected to occur each year	1.0E+00	Operation high frequency

Consequence Classes: defines the different consequence levels that can occur following a failure. The consequence can be related to one or several of the following categories: safety, environmental impact, asset and production / generation. The consequence is normally classified from no impact to catastrophic.

Class	Description of consequences (impact on)				
	Safety	Environment	Operation	Assets	Cost (GBP)
1	Negligible injury or health effects	Negligible pollution or no effect on environment	Negligible effect on production (hours)	Negligible	1k
2	Minor injuries or health effects	Minor pollution / slight effect on environment (minimum disruption on marine life)	Partial loss of performance (retrieval not required outside maintenance interval)	Repairable within maintenance interval	10k
3	Moderate injuries and/or health effects	Limited levels of pollution, manageable / moderate effect on environment	Loss of performance requiring retrieval outside maintenance interval	Repairable outside maintenance interval	100k
4	Significant injuries	Moderate pollution, with some clean-up costs / Serious effect on environment	Total loss of production up to 1 m (GBP)	Significant but repairable outside maintenance interval	1m
5	A fatality	Major pollution event, with significant clean-up costs / disastrous effects on the environment	Total loss of production greater than 1 m (GBP)	Loss of device, major repair needed by removal of device and exchange of major components	10m

Technology Class: Proven technology is considered a technology classified as ‘1 - No new technical uncertainties’. All other classes reflect varying levels of technology novelty.

Application Area	Technology Status		
	Proven	Limited Field History	Unproven
Known	1	2	3
New	2	3	4

Technology Class	Definition
1	No new technical uncertainties
2	New technical uncertainties
3	New technical challenges
4	Demanding new technical challenges

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